1. When $\text{N}_2\text{O}_5(g)$ decomposes as shown below at a fixed temperature, the rate of formation of $\text{NO}_2$ is $3.7 \times 10^{-3}$ M/s.

$$2 \text{N}_2\text{O}_5(g) \rightarrow 4 \text{NO}_2(g) + \text{O}_2(g)$$

What is the rate of loss of $\text{N}_2\text{O}_5$ under these conditions?

A. $9.3 \times 10^{-4}$ M/s  
B. $1.9 \times 10^{-3}$ M/s  
C. $3.7 \times 10^{-3}$ M/s  
D. $7.4 \times 10^{-3}$ M/s  
E. $1.5 \times 10^{-2}$ M/s

2. The rate law for the following reaction is $\text{rate} = k [\text{NO}]^2[\text{H}_2]$.

$$2 \text{NO}(g) + 2 \text{H}_2(g) \rightarrow \text{N}_2(g) + 2 \text{H}_2\text{O}(g)$$

If the concentration of NO is tripled, while everything else is kept the same, what will happen to the rate of the reaction?

A. It remains unchanged.  
B. It triples.  
C. It is reduced by a factor of 3.  
D. It increases by a factor of 6.  
E. It increases by a factor of 9.

3. The experimentally determined rate law for the following reaction is:
rate = k \[Cl_2\]^{1/2}[CHCl_3]

Cl_2(g) + CHCl_3(g) \rightarrow HCl(g) + CCl_4(g)

What is the unit of the rate constant for this reaction?

A. M s\(^{-1}\)
B. M\(^{-1}\) s\(^{-1}\)
C. M\(^{1/2}\) s\(^{-1}\)
D. M\(^{1/2}\) s\(^{-1}\)
E. M\(^{1/2}\) s\(^{-1/2}\)

4. One way enzyme catalysts increase the rate of reactions is by:

A. decreasing the energy of the products.
B. shifting the equilibrium to favor product formation.
C. increasing the temperature during the reaction.
D. decreasing the activation energy of the reaction.
E. increasing the activation energy of the reaction.

5. Which reaction below should have \(\Delta S > 0\) ?

A. 2 \(H_2\) (g) + \(O_2\) (g) \rightarrow 2 \(H_2O\) (g)
B. 2 \(NO_2\) (g) \rightarrow \(N_2O_4\) (g)
C. \(Ag^+\) (aq) + \(Cl^-\) (aq) \rightarrow \(AgCl\) (s)
D. \(BaF_2\) (s) + \(H_2O\) (l) \rightarrow \(Ba^{2+}\) (aq) + 2 \(F^-\) (aq)
E. 2 \(Hg\) (l) + \(O_2\) (g) \rightarrow 2 \(HgO\) (s)

6. Which of the following will have the highest gas-phase entropy at 25\(^\circ\)C?

A. \(H_2\)
B. \(C_2H_6\)
C. \(CH_4\)
D. \(C_3H_8\)
E. \(C_2H_2\)

7. Why do the rates of reactions increase when the concentrations of reactants are increased?
A. There is an increase in the magnitude of the rate constant.
B. The average kinetic energy of the reactants increases.
C. It ensures that all of the reactants will collide with the proper orientation for reaction.
D. It lowers the energy of the transition state.
E. It increases the frequency of collisions.

8. A first-order reaction is 4 times faster at 50°C than it is at 25°C. What is the activation energy of this reaction?

A. 0.576 kJ/mol
B. 5.34 kJ/mol
C. 26.1 kJ/mol
D. 44.3 kJ/mol
E. 52.2 kJ/mol
9. An experiment was run at 298 K and the following data were collected and plotted:

\[
\ln[A] \text{ vs. time}
\]

\[
y = -0.014x - 0.2867
\]

The slope is \(-0.014\) s\(^{-1}\) and the y-intercept is \(-0.2867\). What is the order of the reaction, and what is the half-life?

<table>
<thead>
<tr>
<th>Order</th>
<th>Half-life</th>
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<tbody>
<tr>
<td>A. second</td>
<td>49.5 sec</td>
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<tr>
<td>B. second</td>
<td>0.014 sec</td>
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<tr>
<td>C. first</td>
<td>2.4 sec</td>
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<tr>
<td>D. first</td>
<td>49.5 sec</td>
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<tr>
<td>E. first</td>
<td>0.014 sec</td>
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10. Solid ammonium nitrate (NH\(_4\)NO\(_3\)) is highly soluble in water. When it dissolves, the solution gets cold (i.e., the beaker feels very cold). Based on this information, what are the signs for \(\Delta H\) and \(\Delta S\) respectively?

A. \(\Delta H\) is \(-\), \(\Delta S\) is \(-\)
B. \(\Delta H\) is \(-\), \(\Delta S\) is +
C. \(\Delta H\) is +, \(\Delta S\) is –
D. \(\Delta H\) is +, \(\Delta S\) is +
E. \(\Delta H\) is 0, \(\Delta S\) is 0
11. The following data was collected for the recombination reaction of iodine atoms in the presence of Ar. What is the rate law for this reaction?

\[ 2 \text{I}(g) + \text{Ar}(g) \rightarrow \text{I}_2(g) + \text{Ar}(g) \]

<table>
<thead>
<tr>
<th>[I] (M)</th>
<th>[Ar] (M)</th>
<th>Initial rate (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 \times 10^{-5}</td>
<td>1.0 \times 10^{-3}</td>
<td>8.7 \times 10^{-4}</td>
</tr>
<tr>
<td>2.0 \times 10^{-5}</td>
<td>1.0 \times 10^{-3}</td>
<td>3.5 \times 10^{-3}</td>
</tr>
<tr>
<td>4.0 \times 10^{-5}</td>
<td>1.0 \times 10^{-3}</td>
<td>1.4 \times 10^{-2}</td>
</tr>
<tr>
<td>2.0 \times 10^{-5}</td>
<td>4.0 \times 10^{-3}</td>
<td>1.4 \times 10^{-2}</td>
</tr>
</tbody>
</table>

A. rate = k [I] [Ar]  
B. rate = k [I]^2  
C. rate = k [Ar]  
D. rate = k [I]  
E. rate = k [I]^2[Ar]

12. The progress of a reaction of A → 2 B is shown below. Each white sphere represents 1.0 \times 10^{-2} M of A, each gray sphere represents 1.0 \times 10^{-2} M of B. What is the average rate of disappearance of A during this time interval?

\[ t = 0 \text{ s} \quad t = 35 \text{ s} \]

A. 1.4 \times 10^{-3} \text{ M s}^{-1}  
B. 2.9 \times 10^{-3} \text{ M s}^{-1}  
C. \sim 1.4 \times 10^{-3} \text{ M s}^{-1}  
D. \sim 2.9 \times 10^{-3} \text{ M s}^{-1}  
E. 7.1 \times 10^{-4} \text{ M s}^{-1}  

13. The observed rate law for the reaction: \[ 2 \text{NO}(g) + \text{Br}_2(g) \rightarrow 2 \text{NOBr}(g) \] is
Rate = $k [\text{NO}]^2[\text{Br}_2]$

Which of the following mechanisms is/are consistent with the observed rate law?

**Mechanism I:**
\[
\begin{align*}
\text{NO (g)} + \text{Br}_2 (g) & \rightleftharpoons \text{NOBr}_2 (g) \quad \text{(fast)} \\
\text{NOBr}_2 (g) + \text{NO (g)} & \rightarrow 2 \text{NOBr (g)} \quad \text{(slow)}
\end{align*}
\]

**Mechanism II:**
\[
\begin{align*}
\text{NO (g)} + \text{Br}_2 (g) & \rightarrow \text{NOBr}_2 (g) \quad \text{(slow)} \\
\text{NOBr}_2 (g) + \text{NO (g)} & \rightarrow 2 \text{NOBr (g)} \quad \text{(fast)}
\end{align*}
\]

**Mechanism III:**
\[
\begin{align*}
\text{NO (g)} + \text{NO (g)} & \rightleftharpoons \text{N}_2\text{O}_2 (g) \quad \text{(fast)} \\
\text{N}_2\text{O}_2 (g) + \text{Br}_2 (g) & \rightarrow 2 \text{NOBr (g)} \quad \text{(slow)}
\end{align*}
\]

A. I only  
B. II only  
C. III only  
D. I and III only  
E. II and III only

14. The activation energy for the industrial drying of tomato, an important method of food preservation, is 33.3 kJ/mol. How many times faster does this process proceed at 200°C than at 25°C?

A. 1.2  
B. 5.0  
C. 144  
D. $1.31 \times 10^4$  
E. $7.6 \times 10^{60}$
15. A gas phase reaction is studied and the activation energy and reaction energy are determined. Which of the following reaction profiles is consistent with this information?

\[ E_a = 20 \text{ kJ/mol}, \quad \Delta E = +7.5 \text{ kJ/mol} \]
16. Each line in the graph below represents a different reaction. Rank the reactions in order of increasing activation energy.

A. 1 < 2 < 3
B. 1 < 3 < 2
C. 2 < 3 < 1
D. 3 < 1 < 2
E. 3 < 2 < 1

17. Consider the following reaction:

$$(\text{CH}_3)_3\text{CCl} \text{ (g)} + \text{H}_2\text{O} \text{ (g)} \rightarrow (\text{CH}_3)_3\text{COH} \text{ (g)} + \text{HCl} \text{ (aq)}$$

An organic chemistry student studying this reaction notes that it follows first order kinetics with respect to $(\text{CH}_3)_3\text{CCl}$. He also notes the following while studying the reaction at a high temperature:

$[\text{(CH}_3)_3\text{CCl}] = 4\text{M}$

Rate = 0.0175 M/min

What is the value of the rate constant, $k$, under these conditions?

A. $3.06 \times 10^{-4} \text{ min}^{-1}$
B. $2.26 \times 10^{2} \text{ min}^{-1}$
C. $7.00 \times 10^{2} \text{ min}^{-1}$
D. $4.38 \times 10^{-3} \text{ min}^{-1}$
E. $1.75 \times 10^{-4} \text{ min}^{-1}$
18. Butadiene ($\text{C}_4\text{H}_6$) is used mainly in the production of synthetic rubber. A reaction of $\text{C}_4\text{H}_6$ was studied at 326 °C, and the results ($1/\text{[C}_4\text{H}_6]$ as a function of time) are shown in the figure below.

The $y$-intercept of the plot is 58.1 M$^{-1}$, and the slope of the line is 0.0131 s$^{-1}$. If the experiment is repeated with an initial $\text{C}_4\text{H}_6$ concentration of 0.0325 M, how long would it take to decompose half of the $\text{C}_4\text{H}_6$?

A. $2.35 \times 10^3$ sec  
B. $1.22 \times 10^3$ sec  
C. $3.64 \times 10^3$ sec  
D. $4.21 \times 10^3$ sec  
E. $5.10 \times 10^3$ sec
19. A student studies a first order reaction under several different conditions and gets the results shown in the plot below. Which of the following conclusions about these experiments are correct?

1. Reactions 1 and 2 were done at the same temperature but with different starting concentrations.
2. Reactions 2 and 3 were done at the same temperature but with different starting concentrations.
3. Reaction 2 was done at a lower temperature than reaction 3.

A. only 1 is correct
B. only 2 is correct
C. only 3 is correct
D. 1 and 3 are correct.
E. 2 and 3 are correct.
For the next two questions, consider the following mechanism which involves the oxidation of iodide ion by hydrogen peroxide in acid solution:

Step 1 (slow) \[ \text{H}_2\text{O}_2(\text{aq}) + \text{I}^- (\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{OI}^- (\text{aq}) \]
Step 2 (fast) \[ \text{H}^+ (\text{aq}) + \text{OI}^- (\text{aq}) \rightarrow \text{HOI}(\text{aq}) \]
Step 3 (fast) \[ \text{HOI}(\text{aq}) + \text{H}^+ (\text{aq}) + \text{I}^- (\text{aq}) \rightarrow \text{I}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \]

20. Which of the following statements are true?

A. OI\(^-\) and HOI are catalysts
B. OI\(^-\) and HOI are intermediates
C. OI\(^-\) is a catalyst and HOI is an intermediate
D. HOI is a catalyst and OI\(^-\) is an intermediate
E. There are no catalysts or intermediates in this mechanism.

21. For the mechanism above to be consistent with the kinetic data, what must be the experimental rate law?

A. Rate = \( k \left[ \text{H}_2\text{O}_2 \right] \left[ \text{H}^+ \right]^2 \left[ \text{I}^- \right]^2 \)
B. Rate = \( k \left[ \text{I}_2 \right] \left[ \text{H}_2\text{O} \right]^2 \)
C. Rate = \( k \left[ \text{H}_2\text{O}_2 \right] \left[ \text{I}^- \right] \)
D. Rate = \( k \left[ \text{H}^+ \right] \left[ \text{OI}^- \right] \)
E. Rate = \( k \left[ \text{HOI} \right] \left[ \text{H}^+ \right] \left[ \text{I}^- \right] \)

22. Substance X, a highly toxic chemical that converts into a pleasant ester that smells of elderberries, reacts via first order kinetics with a half-life \( t_{1/2} = 4.2 \) hours. An aromachologist allows a 2M solution of Substance X to react for 10 hours. What concentration of Substance X remains after that time?

A. 1.12 M
B. 0.87 M
C. 0.38 M
D. 0.96 M
E. 0.24 M
23. Consider the following data taken from an important reaction at multiple temperatures:

Given these data, what is the activation energy of this important reaction?

A. 3.52 kJ
B. 4.20 kJ
C. 19.8 kJ
D. 29.7 kJ
E. 34.9 kJ

24. Consider the following reaction:
This reaction proceeds following the rate law: \( \text{Rate} = k[(\text{CH}_3\text{CBr})] \)

At a certain high temperature, this reaction has a half-life of 0.878 seconds. Given these data, what is the reaction rate at this temperature if \( [(\text{CH}_3\text{CBr})] = 0.40 \text{ M} \)?

A. 0.316 M/s
B. 0.472 M/s
C. 0.351 M/s
D. 0.507 M/s
E. 0.214 M/s

25. In organic chemistry, cis/trans isomerism describes the relative orientation of functional groups within a molecule. Alkene containing compound but-2-ene can interconvert from the cis isomer to the trans isomer at 80 °C with an activation energy of 65.0 kJ/mol. At the same temperature with a nitric oxide (NO) catalyst, the activation energy decreases to 27.5 kJ/mol. Assuming the frequency factor is the same for the catalyzed and uncatalyzed reactions, how many times faster is the catalyzed reaction than the uncatalyzed reaction at 80 °C?

A. \( 3.5 \times 10^5 \)
B. \( 2.8 \times 10^{-6} \)
C. \( 5.1 \times 10^8 \)
D. \( 1.0 \times 10^{10} \)
E. \( 1.7 \times 10^{-2} \)
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